High Energy Power & Propulsion Capability Roadmap Status Update

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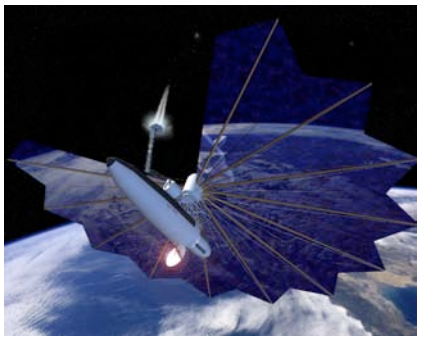
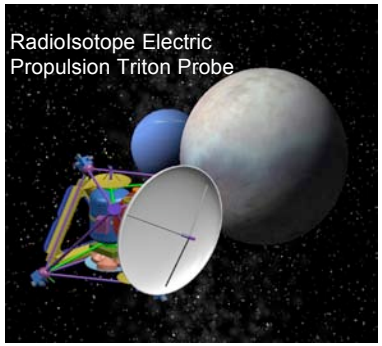
HEP & P Relevance

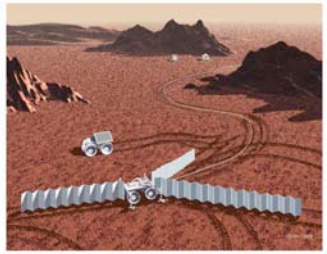
Advanced Planning & Integration Office



SEP/Chemical Mars Transport Stage

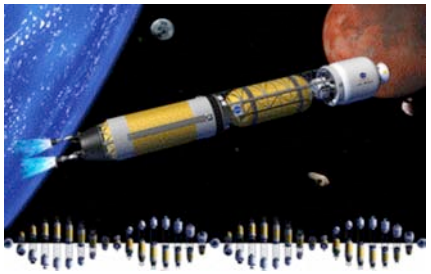


15 MWe NEP Mars Piloted Vehicle

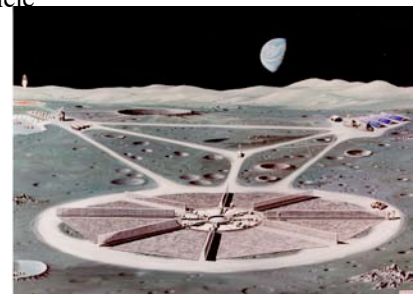


Nuclear Fission Mars Power System
Radiosotope Powered Cart

High Energy Power & Propulsion



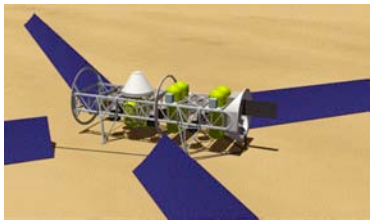
Nuclear Bi-Modal Piloted
Nuclear Thermal Rocket



Nuclear Fission Lunar Power System

Photovoltaic Powered Robotic
Lunar Lander

Radioisotope Powered
Deep Space Probe



Photovoltaic Mars Power System

Photovoltaic Powered Mars Rover

HEP & P Scope/Domain

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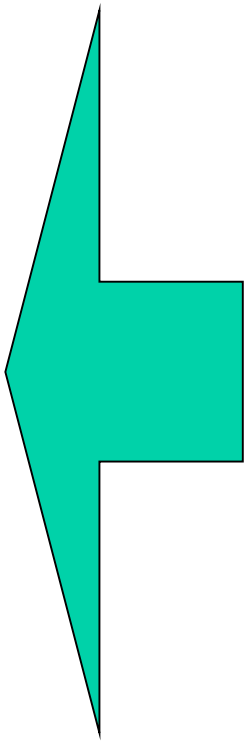
- **Systems Capabilities**
  - Nuclear Fission Power Systems
  - Nuclear Electric Propulsion Systems
  - Nuclear Thermal Propulsion Systems
  - Radioisotope Power Systems
  - Radioisotope Electric Propulsion Systems
  - Solar Power Systems
  - Solar Electric Propulsion Systems
  - Primary Battery/Fuel Cell Power Systems
  - Advanced Concepts (e.g., wireless power transmission)



- **Subsystems/Technology Capabilities**
  - Nuclear Reactors
    - Fuels
    - Materials
    - Controls
    - Shielding
  - Power Conversion Devices
    - Materials
    - Recuperators/Regenerators
  - Heat Rejection Radiators
    - Materials
    - Structures
  - Power Management and Distribution
    - AC-DC converters
    - DC-DC converters
    - Cabling
  - Electric Propulsion Subsystem
    - Thrusters
    - Power Processing Units
    - Tankage and propellant feed systems
  - Photovoltaic arrays
    - Solar cells
    - Concentrator concepts
    - Array blankets
    - Array structures
  - Energy Storage
    - Batteries
    - Regenerative fuel cells
      - Electrolyzers
      - Fuel Cells
      - H2 – O2 tanks
    - Flywhee
  - Guidance and Navigation (In Conjunction with In-Space Transportation Team)
  - Avionics (Address unique nuclear requirements)
  - Vehicle Health Management (Address unique nuclear requirements)

HEP & P Application Areas

- Robotic-Science Spacecraft Power
- Robotic-Science Propulsion (and On-board Power)
- Lunar Surface Power
  - Stationary
  - Mobile
- Mars Surface Power
  - Stationary
  - Mobile
- Human Exploration Propulsion (and On-Board Power)
  - Piloted
  - Cargo

Capability Roadmap Team

Advanced Planning & Integration Office

Co-Chairs

- **NASA: Joseph J. Nainiger, Glenn Research Center**
- **External: Tom Hughes, Penn State, Applied Research Lab**
- **DOE: John (Jack) P. Wheeler, DOE HQs**

Team Members

- **Government**

  Elaine Kobalka, NASA Glenn Research Center
  Stan Borowski, NASA Glenn Research Center
  Jose Davis, NASA Glenn Research Center
  Jeff George, NASA Johnson Space Center
  Rao Surampudi, Jet Propulsion Laboratory
  Sherrell Greene, Oak Ridge National Laboratory
  George Schmidt, NASA Marshall Space Flight Center
  Bob Wiley, DOE HQ
  Rebecca Richardson, DOE HQ
  Wayne Bordelon, NASA Marshall Space Flight Center

- **Industry**

  Samit K. Bhattacharyya, President, RENMAR Enterprises
  Gary L. Bennett, Consultant
  Dave Byers, Consultant

- **Academia**

  James Gilland, Ohio Aerospace Institute
  Henry W. Brandhorst, Jr., Director, Space Research Institute, Auburn University

Coordinators

Directorate: Overall: Betsy Park, ESMD, Technical: Raynor Taylor, ESMD, (Day-to Day, Jay Jenkins, ESMD)

APIO: Perry Bankston, Jet Propulsion Laboratory

HEP & P Capability Roadmap Process and Approach - 1

- **Have divided Capability Roadmap team into 5 sub-teams**
  - **Fission Systems**
    - Lead: Sherrell Greene, Oak Ridge National Lab
  - **Radioisotope Systems**
    - Lead: Bob Wiley, DOE HDQs
  - **Solar Systems**
    - Lead: Henry W. Brandhorst, Jr., Auburn University
  - **Energy Storage**
    - Lead: Rao Surampudi, Jet Propulsion Lab
  - **Advanced Concepts**
    - Lead: Henry W. Brandhorst, Jr., Auburn University

HEP & P Capability Roadmap Process and Approach - 2

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- **Each sub-team has been given the same set of initial requirements from which more detailed requirements will be determined**
  - Lunar Roadmap Framework: Short Stay
  - Lunar Roadmap Framework: Long Stay
  - Lunar DRM TP2001
  - Lunar Robotic Science DRM
  - Mars Roadmap Framework
  - Mars FY03 NEP Architecture
  - Mars NASA SP2
  - Mars NASA SP-6107
  - Mars TP 2002
  - Mars Robotic Science DRM
  - Outer Solar System Science DRM

Roadmap Process and Approach - 3

- Each sub- team is in the process of establishing the State-of-the-Art (SOA) or State-of-the-Practice (SOP) for their particular area (At the systems, subsystems, and technology level)
- Derived assumptions/requirements will be scrubbed as a total team
- Each sub-team, based upon derived assumptions/requirements, will lay out path for each capability/system and supporting technology development required to meet the NASA need (both in time as well as performance)
- This path will indicate major decision points and milestones
- Team is interacting/iterating with several other capability roadmap teams
- Team will need to interact/iterate extensively with Strategic Roadmap Teams

Questions/Issues for SRC-2

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- We need "official" set of Agency key missions up to 2030+ (probably out to 2040) with approximate dates that capabilities will be needed
  - What are the characteristics of those missions that will define capability characteristics (science instruments, landing sites, crew size, etc.)
  - For those missions, what are the critical requirements/metrics that drive the capabilities (e.g., power level, mission duration, desired/required trip time, etc.)
- How does SRC-2 view the lunar program as a test-bed for Mars?

Backup

HEP & P Sub-Teams and Members

- **High Energy Storage**
  - Surampudi (L)
    - Davis
    - Brandhorst
    - Bennett
    - Schmidt
- **Solar**
  - Brandhorst (L)
    - Davis
    - Surampudi
    - Byers
    - Gilland
    - George
    - Schmidt
- **Advanced Concepts**
  - Brandhorst (L)
    - Byers
    - Gilland
- **Nuclear – Wheeler (L)**
  - **Nuclear Fission**
    - Greene (L)
      - Wheeler
      - Borowski
      - George
      - Schmidt
      - Bennett
      - Byers
      - Gilland
      - Hughes
      - Batacharyyia
      - Bordelon
  - **RPS**
    - Wiley (L)
      - Surampudi
      - Schmidt
      - Bennett
      - Byers
      - Gilland
      - Hughes
      - Davis

Radioisotope Power Systems Breakdown Structure

- GPHS Modules
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection System/Housing
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling

Nuclear Electric Propulsion Systems Breakdown Structure

- Nuclear Fission Reactor
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection Systems
  - Materials
  - Structure
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling
- Electric Propulsion Subsystem
  - Thrusters
  - Power Processing Units
  - Tankage and propellant feed system
- Guidance and Navigation (In Conjunction with In-Space Transportation Team)
- Avionics (Address unique nuclear requirements)
- Vehicle Health Management (Address unique nuclear requirements)

Nuclear Thermal Propulsion Systems Breakdown Structure

- Nuclear Fission Reactors
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion (For Bi-Modal options)
- Fuel Tanks (Address materials considerations unique to nuclear radiation environment)
- Pumps (Address technology issues related to long run times and nuclear radiation environment)
- Nozzles (Address technology issues related to long run times and nuclear radiation environment)
- Guidance and Navigation (From In-Space Transportation team)
- Avionics (Address unique nuclear requirements)
- Vehicle Health Management (Address unique nuclear requirements)

Photovoltaic Power Systems Breakdown Structure

- **Photovoltaic arrays**
  - Solar cells
  - Concentrator concepts
  - Array blankets
  - Array structures
- **Energy Storage**
  - Batteries
  - Regenerative fuel cells
    - Electrolyzers
    - Fuel Cells
    - H2 – O2 tanks
  - Flywheel
- **Power Management and Distribution**
  - DC-DC converters
  - Cabling
  - Charge/Discharge control
  - Shunt regulator

Nuclear Fission Power Systems Breakdown Structure

- Nuclear Fission Reactor
  - Fuels and cladding
  - Materials
  - Controls
  - Shielding
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection Systems
  - Materials
  - Structure
- Power Management and Distribution
  - AC-DC converters
  - DC-DC converters
  - Cabling

Radioisotope Electric Propulsion Systems Breakdown Structure

- GPHS Modules
- Power Conversion Devices (various types – Brayton, Stirling, thermoelectrics, etc.)
- Heat Rejection System/Housing
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HEP & P Capability Roadmap
Milestones to Date

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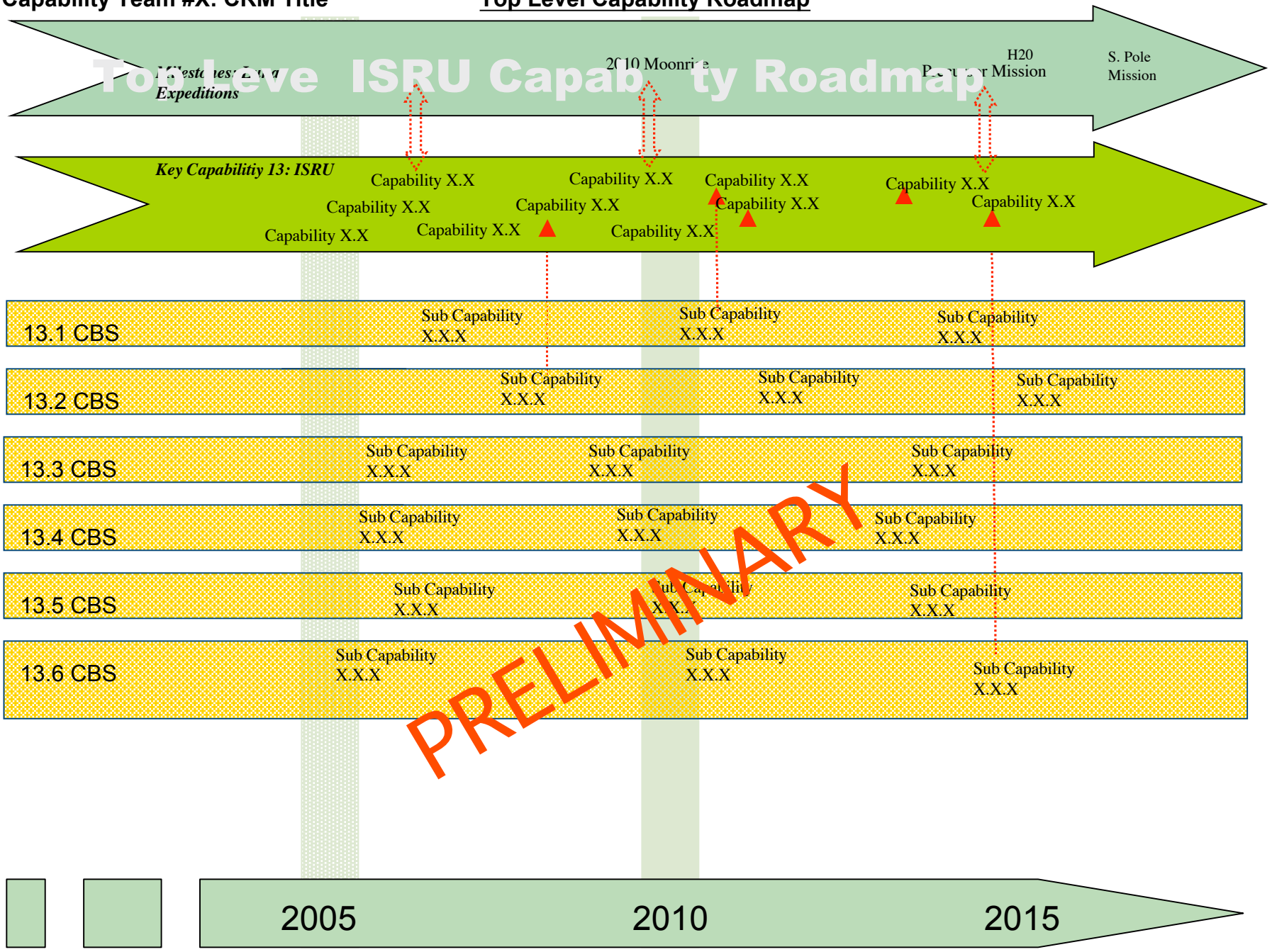
• Team Formation	Oct04
• Initiate Weekly Team Telecons	Nov04
• APIO Workshop to Collect Ext. Input	Nov04
• 1st Team Meeting	Dec04
• Fission Sub-Team Meeting	Jan04
• Solar Sub-Team Meeting	Jan04
• Energy Storage Sub-Team Meeting	Jan04
• 2nd Team Meeting	Feb04

Key Dates Upcoming

- Roll-up of sub-team roadmaps, late February
- 1st Draft of Roadmap To Academy (Presentation Product Due) March 31

Capability Team #X: CRM Title

Top Level Capability Roadmap



Sub-Capability 1.1. CBS Title Roadmap

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DRAFT EXAMPLE CAPABILITY DECISION ROADMAP